Mars Surface Crew Operations Study

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http://www.nasa.gov/directorates/heo/reports.html

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HAT / EMC Mars Surface Team

Study Overview

- Develop a Point-of-Departure (POD) Concept of Operations (ConOps) for a crewed Mars long-stay science-driven surface mission
- For Science Information
  - Mars Exploration Program Advisory Group (MEPAG) Human Exploration of Mars-Science Analysis Group (HEM-SAG) document (2008) *Planning for the Scientific Exploration of Mars by Humans*
  - Science disciplines assessed
    - Geology
    - Geophysics: Planetary, regional, local-scale
    - Atmospheric & Climate Science: Atmosphere, climate, atmosphere-surface interactions
    - Astrobiology
  - Created a "workbook" to gather science discipline information from MEPAG HEM-SAG team
  - Held "interviews" for each science discipline
  - Hosted a series of special SME briefings
    - Deep Drilling (on Earth and Mars)
    - Biocontainment of Earth and Mars Pathogens
    - Mars Planetary Protection

Instrument	Measurements / Investigations	Geology	Planetary-scale Geophysics	Local-scale Geophysics	Climate and Atmosphere	Atmosphere-Surface Interactions	Polar Drilling	Astrobiology	Capabilities/details
Active EM source				✓					Various flexible loops/dipoles deployed 5m-100m baselines
	EM induction (conductivity profile)			✓					
	EM sounding (conductivity profile)			✓					
	Active EM (sounding? Or induction?)			✓					
	Subsurface mapping via EM sounding			✓					
??	ULF EM induction (conductivity profile)		✓						
Seismometer		✓	✓	✓					3-axis system, two long-period and 1 MEMS-based short period
	Seismology		✓						
	Active seismic			✓					
	Seismic stations	✓							
??	Reflection seimsology			✓					
GPR		✓		✓					High frequency magnetic-coil based seismometers (3-4 units)
Drill (break out into depth? More than one type?)		✓		✓					
	Drilling	✓							
	Instrumented drilling			✓					
	Sampling of Noachian to Amazonian deposits through soft drilling (~1 meter deep) along outcrops, or deep drilling to capture information in the sedimentary record				✓	✓			
Sample Collection (rake, bags, hammer, "grabber")		✓							
	Sample collection at multiple latitudes/environments	✓							
	Sampling along traverses	✓							
	Sampling of diverse mineralogy	✓							
	Stratigraphic sample collection	✓							
	Ejecta sampling	✓							
	Thorough sampling of diverse rocks	✓							
	Extensive sampling traverses	✓							
	Returned samples of dust from significant lag deposits						✓		
	Traverse sampling along glaciers	✓							

- Workbook Information Categories
  - Sampling location: Fixed site, many sites
  - Drilling depth (meters)
  - Landing site proximity: Local (<10 km), Regional (>10 km)
  - Data collection approach: Stationary, traverse
  - Data collection resources: Passive, active
  - Data analysis location: In-situ surface, in-situ subsurface, surface lab, Earth lab
  - Data/sample return: Data returned, sample returned (in sealed container), sample returned (requires special environment)
  - Mission Phase 1 - Phase 6: Robot only, Crew + robot, Crew only
  - How clean
  - Data rate/frequency
  - Precursor measurements required?
  - Operational notes/recommendations

- **Drilling:** Mr. Roy Long, Ultra-Deepwater Technology Manager, Strategic Center for Natural Gas and Oil, US Department of Energy, National Energy Technology Laboratory
- **Biocontainment of Earth & Mars Pathogens:** Dr. Katharine Rubins, JSC, Pathogen , JSC Astronaut Office, Molecular & Cancer Biology
- **Planetary Protection:** Dr. Catharine A. Conley, NASA Planetary Protection Officer, HQ, Plant Biology

Study Overview

4) Held an "Educational Forum"
   - EVA and Suit Ports
   - Crew Medical Issues Regarding Mars Toxicology
   - Crew Safety
   - Mars Sample Handling
   - Planetary Protection

5) Created a series of "guiding questions" in five topics of interest to Mars ConOps development:
   - Returning Mars samples with the crew
   - Crew waste storage, transfer, and disposal
   - Pressurized cabin operations
   - Nominal EVA operations
   - Sample handling on the surface by the crew

6) Toured Sample Curation Laboratories at JSC

7) Conducted a number of "Special Studies"
   - Commodity Cache Feasibility Study
   - Traverse Planning and Mobility Study
   - Mars Laboratory and Sample Handling Study
   - Integrated Surface Power Strategy Study
   - Integrated Drilling Strategy Study
   - Statistical Modeling Study

DOT Membership

Primary DOT Core Membership

Larry Toups	JSC	Co Lead
Marianne Bobskill	LaRC	Co Lead
Steve Hoffman	JSC	ConOps Development Lead
Dave Reeves	LaRC	ConOps Development Lead
Michelle Rucker	JSC	Special Studies Lead
Dave North	LaRC	Special Studies Lead

Science Discipline Leads / POCs

Dr. Dean Eppler	JSC	Geology
Dr. Mary Sue Bell	JSC	Geology
Dr. Paul Niles	JSC	Geology
John Gruener	JSC	Geology
Dr. Nicholas Schmer	GSFC	Geophysics
Dr. Joel Levine	College of W&M	Atmosphere &Climate Science
Dr. Peter Doran	UI- Chicago	Astrobiology
Dr. Jennifer Eigenbrode	GSFC	Astrobiology
Dr. Craig Kundrot	JSC	Bioastronautics / HRP
Dr. Catharine Conley	HQ	Planetary Protection
Dr. Margaret Race	SETI Institute	Planetary Protection
Michael Calaway	JSC	Sample Collection, Curation, & Contamination Control

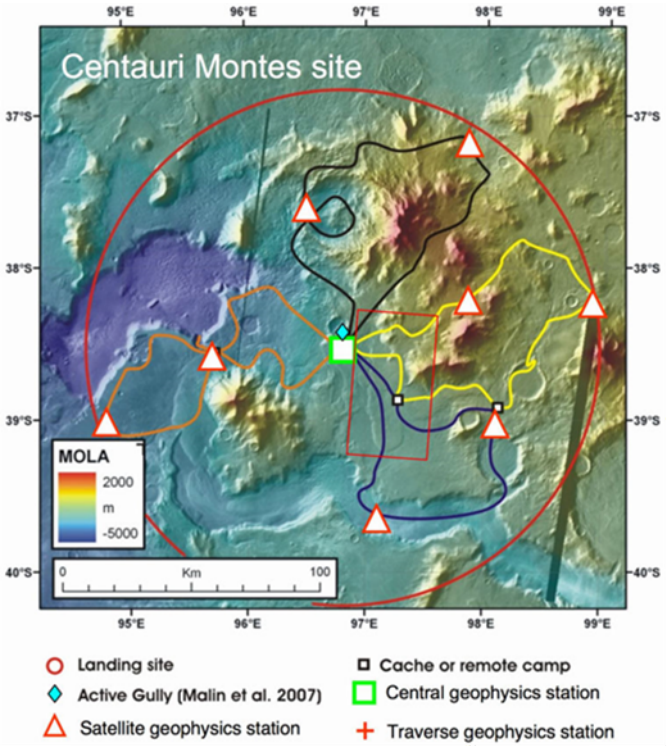
Primary DOT Support

Matt Simon	LaRC	Special Studies - Habitation
Dale Arney	LaRC	Capabilities Team Interface
Sharon Jefferies	LaRC	Capabilities Team Interface
Roger Lepsch	LaRC	ConOps Development
Kevin Larman	LaRC	ConOps Development
Kevin Earle	LaRC	ConOps Development
Dave Helton (ACL)	LaRC	Graphics
David Coan	JSC	Special Studies - EVA
Horacio de la Fuente	JSC	Special Studies
Steve Rader	JSC	ConOps Development
Natalie Mary	JSC	Special Studies - EVA
Ryan Whitley	JSC	Transportation Team Interface
Alida Andrews	JSC	Special Studies-Statistical Modeling
Rob Mueller	KSC	ConOps Development
Mark Lupisella	GSFC	Science & ConOps Development
Kendall Brown	MSFC	Mars Lander Interface
Phillip Nerren	MSFC	Special Studies
David Smitherman	MSFC	Special Studies - Habitation
Brian Wilcox	JPL	Special Studies - Robotics
Scott Howe	JPL	Special Studies - Robotics & Habitation

ConOps Development

- Four of the 58 candidate Mars landing sites identified in the HEM-SAG report were selected for study
  - One of these four candidate sites, Centauri Montes, was analyzed in detail and served as the basis for development of the ConOps

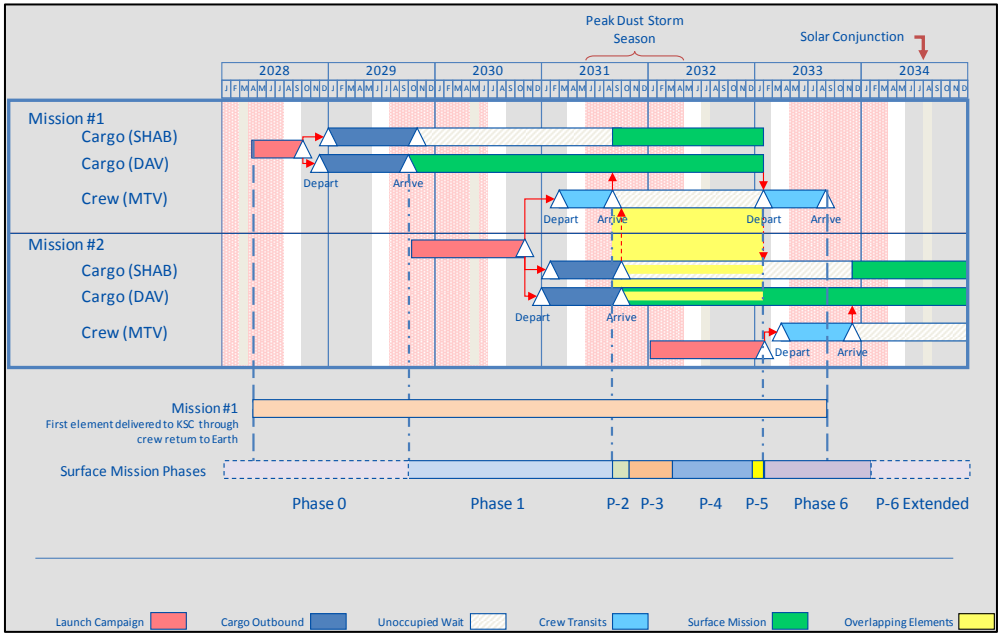
– Assumed
  – A centrally located habitat with volume & resources allocated for science
  – Two pressurized rovers for long-range traverses with field work & basic analytical equipment
  – Two unpressurized rovers = walk-back (~15 km radial distance)
  – Low-latency telerobotic operations
  – Samples returned to primary habitat
  – Considered drilling
  – Nuclear power plant
  – ISRU plant at landing site, operational prior to crew
  – 1 MT downmass allocated for science equipment – does not include rovers, habitat, labs
  – 6 crew – needs re-analysis assuming 4 crew
  – Key groundrules & assumptions: EVA Limits, Work Day, Habitat & Rover operational pressure…



Potential traverses for human exploration

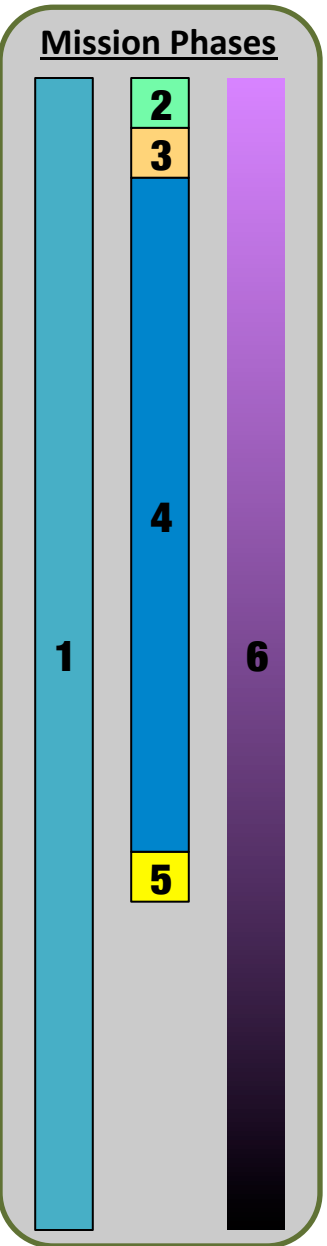
Mission Phases for Notional DRM 5/DRM 9-based Mars Exploration

- **Phase 0 – Prior to Cargo Landing**
  - Observations and investigations of the landing site by previously deployed orbital and surface assets
  - Characterize habitability, including potential special regions
- **Phase 1 – Post Cargo Landing (~2.25 Years)**
  - Cargo Landing
  - FSPS and ISRU deployment
  - Exploration by robotic assets, micro-climate monitoring
  - Final crewed landing site selection
- **Phase 2 – Crew Landing & Acclimation (~30 Sols)**
  - Crew Landing and acclimation to Mars gravity environment
  - Additional deployment of assets and local science investigations as time and capabilities permit
- **Phase 3 – Local Exploration (~30 Sols)**
  - EVAs within local area (~10 km) to set up central stations and complete initial science objectives
  - Deployment of Deep drill system
- **Phase 4 – Regional Exploration (~410 Sols)**
  - Up to 19 separate 15-sol traverses with 2 SPRs
  - Mobility extends up to ~200 km from landing site
  - Sample analysis and follow-on local investigations continue
- **Phase 5 – Preparation for Ascent (~30 Sols)**
  - Final curation of samples and preparation of MAV
  - Crewed Launch with contingency window
- **Phase 6 – Post Crew Departure**
  - Robotic assets continue exploration



The figure above illustrates the relative sequence of each phase with trajectory data for a Mars surface mission set to occur in the early 2030 time frame.

Notional Phase 0 Definition: Prior to Cargo Landing

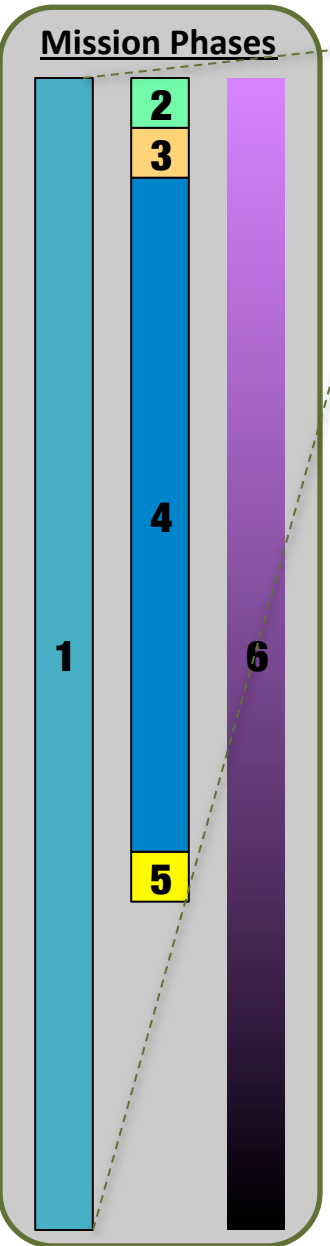


Phase 0 Activities

- **Identify potential deep drill sites**
- **Identify potential crewed landing sites**
  - Cargo lander within 1 km of crewed site
- **Identify cargo landing site**
  - Potential FSPS sites & ISRU location
- **Identify potential "Special Regions"**
- **Identify potential deep drill sites- remove**
- **Map preliminary traverse routes**
- **Identify potential sites for central scientific station(s) deployment**
- **Deploy orbital communications relay in areostationary orbit**
  - Consider other orbiting assets that could potentially help with navigation and communications?

FSPS = Fission Surface Power System
ISRU = In-Situ Resource Utilization

Notional Phase 1 Definition: Post-Cargo Landing

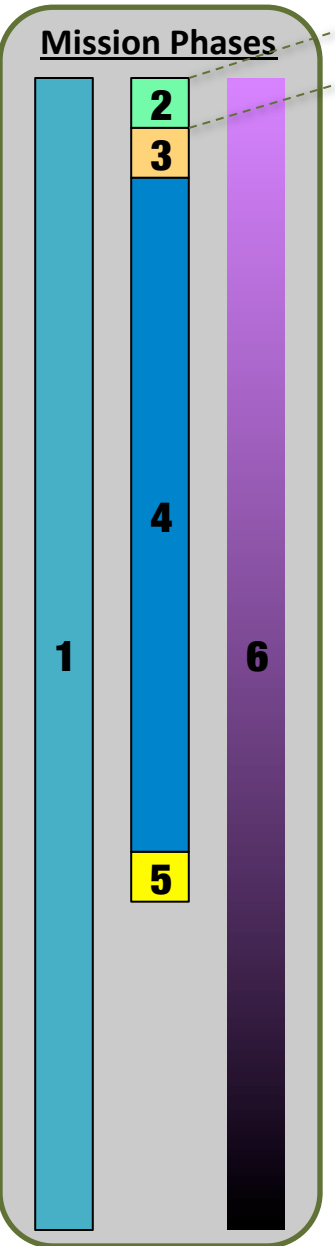


Phase 1 Activities (~ 2.25 years)

- Post landing safing of propulsion systems
- Verify and test of payload unloading system
- Deploy PUP and PUP array
- Deploy & charge FSPS mobility system
- Scout potential FSPS sites and final selection
- Offload, move, deploy, and start up FSPS, including cable runs
- Start ISRU plant
- Produce, deliver, and store MAV propellant
- Scout potential crewed landing sites and make final selection
- Deploy mobile environmental monitoring stations at notional crewed landing site
- Initial scout of deep drilling location
- Site/traverse scouting, mapping, and initial exploration

PUP = Portable Utility Pallet
ISRU = In-Situ Resource Utilization
MAV = Mars Ascent Vehicle

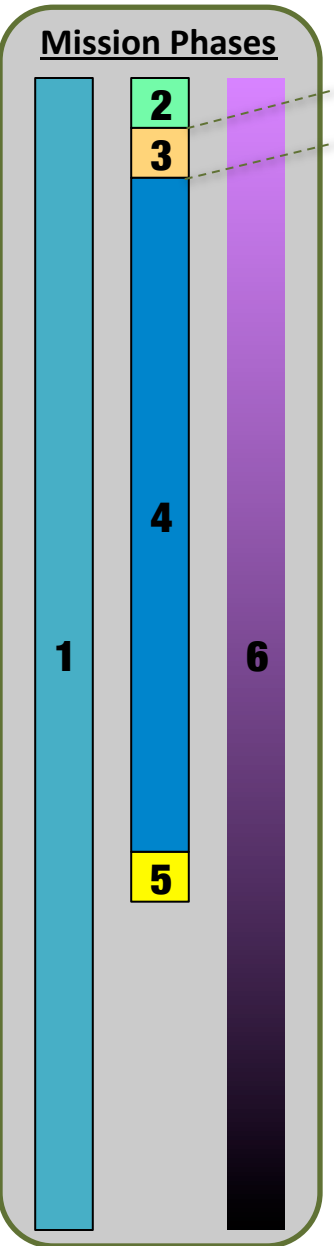
Notional Phase 2 Definition: Crew Acclimation



Phase 2 Activities (~ 30 sols [TBR])

- Crewed landing
- No nominal EVA activities
- Crew exercise and acclimation activities
- Medical life science tests (baseline and on-going)
- (Telerobotically?) connect newly delivered surface assets to pre-existing power grid
- Check out habitation systems
- Check out science systems
- Final outfitting and setup of habitation/lab equipment
- (Telerobotically?) check out and deploy initial surface systems
- Perform telerobotic scouting
- Test for clearance of crew for EVAs by crew health officer

Notional Phase 3 Definition: Local Exploration



Phase 3 Activities (~ 30 sols)

- **Deploy central science station(s) (geophysics, atmosphere, etc.)**
- **Perform initial atmospheric & climate science activities**
  - Initial balloon campaign
  - Initial “chemistry” campaign
  - Lab analysis to calibrate future measurements
- **Test crew mobility systems**
- **Deploy communications tower**
- **Check out MAV**
- **Perform initial exploration and mapping of local area**
  - Geologic context
  - Shallow drilling
  - Geophysics
- **Select deep drill location**
- **Deploy deep drill system**

Notional Phase 3 Definition: Local Exploration

- Operations
  - Set up / deploy science payloads
  - Test pressurized and unpressurized rovers for operational readiness
  - Carry out local scientific investigations and traverses using teleoperations, EVA suits, unpressurized rovers, or pressurized rovers
  - Teleoperate rovers further along the traverse paths to characterize environments "over the horizon" e.g. to avoid inadvertent trespass into special regions
  - Crater Traverse: For the Centauri Montes site, the HEM-SAG report identified a short traverse near the landing site to explore a crater rim on which signs of liquid water have been observed
    - Involves shallow drilling
    - Deploying geophysics instruments (e.g. geophones, sounders, etc.) to verify and locate a subsurface water source
  - Deploy Deep Drill: Two crew traverse to drill site towing the drill equipment, crew stays The crew at drill site, lives in rover for 3 sols during deployment
  - Conduct first balloon campaign: Perform atmospheric & climate science studies using tethered and un-tethered balloons that need to be deployed periodically throughout the mission
  - IVA lab analysis and maintenance: Remainder of time allotted to IVA maintenance and lab analysis.

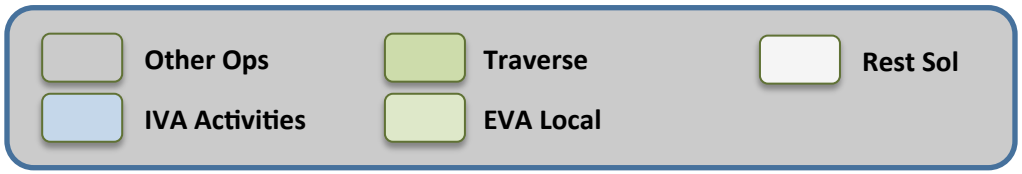
Notional Local Exploration (Phase 3) ConOps (1 of 2)

Sol	Crew 1 & 2	Crew 3 & 4	Crew 5 & 6
1	Local Exploration @ Landing Site	Test/Maintain/Stock Mobility Systems	Deploy Communications Tower
2	Test/Maintain/Stock Mobility Systems	Local Exploration @ Landing Site	Test/Maintain/Stock Mobility Systems
3	Deploy central science station	Lab Analysis / Maintenance	Local Exploration @ Landing Site
4	Lab Analysis / Maintenance	Checkout/Maintain ISRU	Lab Analysis / Maintenance
5	Test/Maintain Mars Ascent Vehicle	Lab Analysis / Maintenance	Test/Maintain Mars Ascent Vehicle
6	Lab Analysis / Maintenance	EVA Habitat Maintenance	Lab Analysis / Maintenance
7	Rest Sol	Rest Sol	Rest Sol
8	EVA Rover Maintenance	Maintain/Stock Mobility Systems	EVA Rover Maintenance
9	Crater Traverse Planning & Prep	Crater Traverse Planning & Prep	Crater Traverse Planning & Prep
10	Lab Analysis / Maintenance / Mission Ops	Crater Traverse (< 10 km of Landing Site)	Crater Traverse (< 10 km of Landing Site)
11			
12			
13			
14	Rest Sol	Rest Sol	Rest Sol
15	EVA Rover Maintenance	Lab Analysis / Maintenance	Lab Analysis / Maintenance

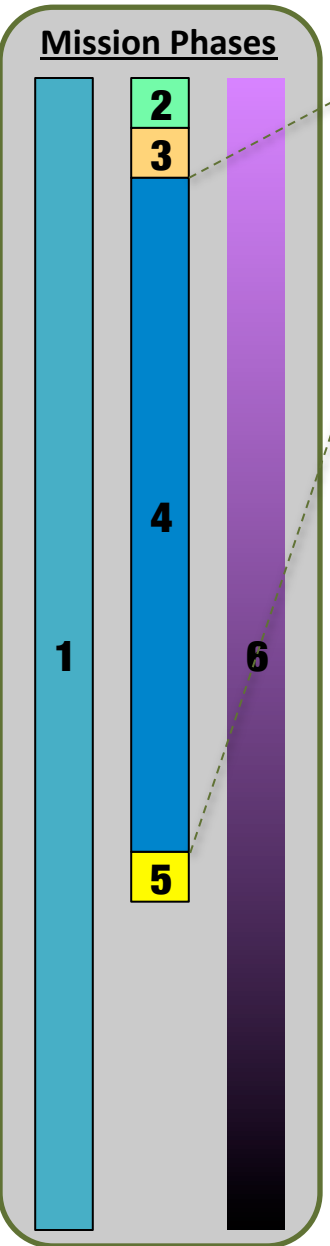
Other Ops
IVA Activities
Traverse
EVA Local
Rest Sol

Notional Local Exploration (Phase 3) ConOps (2 of 2)

Sol	Crew 1 & 2	Crew 3 & 4	Crew 5 & 6
16	Lab Analysis / Maintenance	Lab Analysis / Maintenance	EVA Rover Maintenance
17	Rest Sol	Rest Sol	Rest Sol
18	Local Exploration Planning & Prep	Local Exploration Planning & Prep	Lab Analysis / Maintenance
19	Maintain/Stock Mobility Systems	Maintain/Stock Mobility Systems	
20	Local Exploration (< 10 km of Landing Site)	Local Exploration (< 10 km of Landing Site)	Lab Analysis / Maintenance / Mission Ops
21			
22			
23			
24	Rest Sol	Rest Sol	Rest Sol
25	Deep Drill Planning & Prep	Lab Analysis / Maintenance	Lab Analysis / Maintenance
26	Maintain/Stock Mobility Systems		Balloon Campaign Planning & Prep
27	Deploy/Test of Deep Drill	Lab Analysis / Maintenance / Mission Ops	Balloon Campaign
28			
29			
30	Rest Sol	Rest Sol	Rest Sol



Representative Notional Phase Definition: Phase 4 – Regional Exploration



Phase 4 Activities (~ 410 sols)

- **Traverses**
- **Balloon and chemistry campaigns**
- **Lab analysis and sample curation**

- Over the course of Phase 4, four different paths are traversed. **Each traverse involves two pressurized rovers, each rover carrying two crew.**
- An *initial characterization* (recon) traverse is completed for each traverse path with **nine other 15-sol traverses** available for more in-depth investigations.
- *Follow-on traverses* are planned and finalized after all initial traverses are complete.
  - *Geology/Geophysics* focused
  - *Shallow-drilling* focused

Traverse 1:
Route Characterization
(23 sites, 2 hours each)

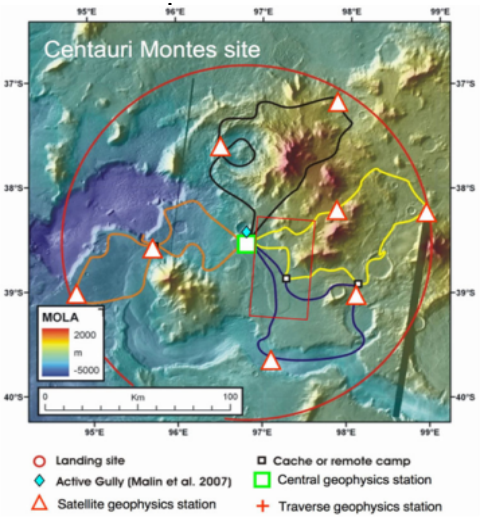
Potential Follow-on # 1:
In-Depth Investigations:
Geophysics-focused
(6 sites, 8 hours each)

Potential Follow-on #2:
In-Depth Investigations:
Shallow drilling-focused
(3 sites, 16 hours each)

Traverse Planning

- **Initial Recon Traverse**
  - Objective
    - Drive the entire traverse route
    - Collect initial context samples and imagery for general route characterization
    - Deploy MET stations
  - Methodology
    - Drive between sites while collecting imagery and other rover-mounted measurements
    - 2 hour (TBR) short stop EVAs to collect samples, perform targeted imagery and spectrometry, and deploy MET stations
    - Actual drive times and number of EVA sites is TBD
    - The following shows the maximum number of EVAs based on EVA constraints
      - 15 sols
      - 23 x 2-hour EVAs
      - 4 MET station deployments
      - ~200-300 km traversed

- **Follow On Traverses**
  - "Flexecution"
    - Flexible execution: Hypothesis-driven objectives and mission plans are defined, but are subject to continual modification throughout the mission as warranted by samples and information gathered
  - Follow on traverses defined based on initial recon traverses
  - Multiple example traverses were defined in order to understand EVA times and possible equipment needs
    - Two samples follow the Recon traverse



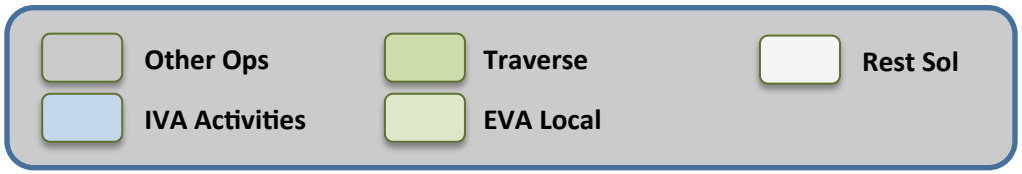
Four Potential Centauri Montes traverses (from MEPAG HEM-SAG)

Initial Recon Traverse: Route Characterization

23 Sites, 2 Hours EVA at each site

Sol 1	Sol 2	Sol 3	Sol 4	Sol 5	Sol 6	Sol 7	Sol 8
Traverse	Site Sweep: (MET Install)	Site Sweep: (Spectrometer)	Site Sweep: (Spectrometer)	Site Sweep: (Spectrometer)	Rest Sol	Site Sweep: (Spectrometer)	Site Sweep: (Spectrometer)
Traverse	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Rest Sol	Traverse / IVA Characterization	Traverse / IVA Characterization
Traverse	Site Sweep: (Spectrometer)	Site Sweep: (Spectrometer)	Site Sweep: (Spectrometer)	Site Sweep: (MET Install)	Rest Sol	Site Sweep: (Spectrometer)	Site Sweep: (Spectrometer)
Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Rest Sol	Traverse / IVA Characterization	Traverse / IVA Characterization

Sol 9	Sol 10	Sol 11	Sol 12	Sol 13	Sol 14	Sol 15
Site Sweep: (Spectrometer)	Site Sweep: (Spectrometer)	Rest Sol	Site Sweep: (Spectrometer)	Site Sweep: (Spectrometer)	Site Sweep: (Spectrometer)	Site Sweep: (MET Install)
Traverse / IVA Characterization	Traverse / IVA Characterization	Rest Sol	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse
Site Sweep: (Spectrometer)	Site Sweep: (MET Install)	Rest Sol	Site Sweep: (Spectrometer)	Site Sweep: (Spectrometer)	Site Sweep: (Spectrometer)	Traverse
Traverse / IVA Characterization	Traverse / IVA Characterization	Rest Sol	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse / IVA Characterization	Traverse



In-Depth Investigations: Geology/Geophysics Focus

6 Sites, 8 Hours Each

Sol 1	Sol 2	Sol 3	Sol 4	Sol 5	Sol 6	Sol 7	Sol 8
Traverse	EVA Wrap	IVA Characterization	EVA Wrap	IVA Characterization	Rest Sol	EVA Wrap	IVA Characterization
Traverse	Local Seismometry	Traverse	Local Seismometry	Traverse	Rest Sol	Local Seismometry	Traverse
Traverse	Surface Sampling	Traverse	Surface Sampling	Traverse	Rest Sol	Surface Sampling	Traverse
IVA Characterization	Surface Measurements	IVA Characterization	Surface Measurements	IVA Characterization	Rest Sol	Surface Measurements	IVA Characterization

Sol 9	Sol 10	Sol 11	Sol 12	Sol 13	Sol 14	Sol 15
EVA Wrap	IVA Characterization	Rest Sol	EVA Wrap	IVA Characterization	EVA Wrap	IVA Characterization
Local Seismometry	Traverse	Rest Sol	Local Seismometry	Traverse	Local Seismometry	Traverse
Surface Sampling	Traverse	Rest Sol	Surface Sampling	Traverse	Surface Sampling	Traverse
Surface Measurements	IVA Characterization	Rest Sol	Surface Measurements	IVA Characterization	Surface Measurements	Traverse

Other Ops
IVA Activities
Traverse
EVA Local
Rest Sol

In-Depth Investigations: Shallow Drilling Focus

3 Sites, 16 Hours Each

Sol 1	Sol 2	Sol 3	Sol 4	Sol 5	Sol 6	Sol 7	Sol 8
Traverse	EVA Wrap	Rest Sol	EVA Wrap	IVA Characterization	Traverse	EVA Wrap	Rest Sol
Traverse	Local Seismometry	Rest Sol	Surface Measurements	Traverse	Traverse	Local Seismometry	Rest Sol
IVA Characterization	Set-up Drill	Rest Sol	Target of Opportunity	Traverse	IVA Characterization	Set-up Drill	Rest Sol
IVA Characterization	Surface Sampling	Rest Sol	Retrieve Drill and sample	Traverse	IVA Characterization	Surface Sampling	Rest Sol

Sol 9	Sol 10	Sol 11	Sol 12	Sol 13	Sol 14	Sol 15
EVA Wrap	IVA Characterization	Traverse	EVA Wrap	Rest Sol	EVA Wrap	IVA Characterization
Surface Measurements	Traverse	Traverse	Local Seismometry	Rest Sol	Surface Measurements	Traverse
Target of Opportunity	Traverse	IVA Characterization	Set-up Drill	Rest Sol	Target of Opportunity	Traverse
Retrieve Drill and sample	Traverse	IVA Characterization	Retrieve Drill and sample	Rest Sol	Retrieve Drill	Traverse

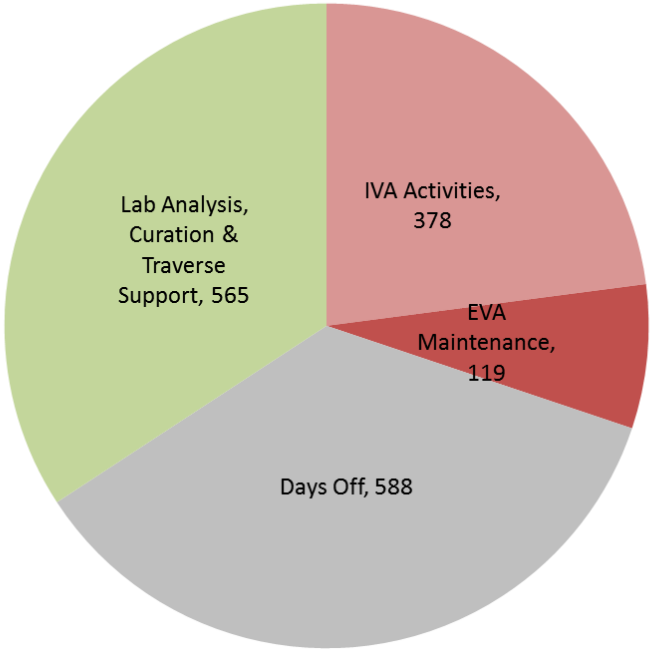
Other Ops
IVA Activities
Traverse
EVA Local
Rest Sol

Phase 4 Summary

- **High-level Sequence of Events**
  - 15 sol traverse
  - 3 sol balloon and chemistry campaign for Atmospheric & Climate Science
  - 7 sols of rest
  - 7 sols of analysis and traverse preparation
  - Sequence is repeated (~13 times)

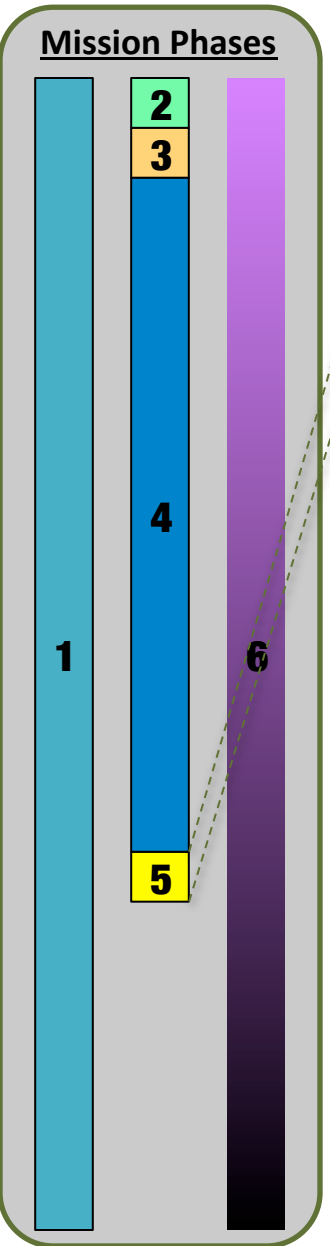
- **Results**
  - 13 Traverses: 4 Recon + 9 Follow-up
  - 5 Balloon and Chemistry Campaigns
  - 1,650 crew-sols in the habitat for analysis, curation, maintenance, house keeping, planning, local exploration, etc.
  - 14 full weeks "off"
  - 28 sols after final traverse for final analysis and curation

Phase 4 Habitat Operations (crew-sols)



7 sols	Initial traverse preparation
15 sols	Recon Traverse 1
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Recon Traverse 2
3 sols	2nd Balloon campaign
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Recon Traverse 3
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Recon Traverse 4
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 1
3 sols	3rd Balloon campaign
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 2
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 3
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 4
3 sols	4th Balloon campaign
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 6
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 7
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 8
3 sols	5th Balloon campaign
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Follow-up Traverse 9
7 sols	Week off
7 sols	Analysis / Preparation
15 sols	Traverse or further analysis
7 sols	Week off
3 sols	6th Balloon campaign
11 sols	Final analysis and curation
7 sols	Week off

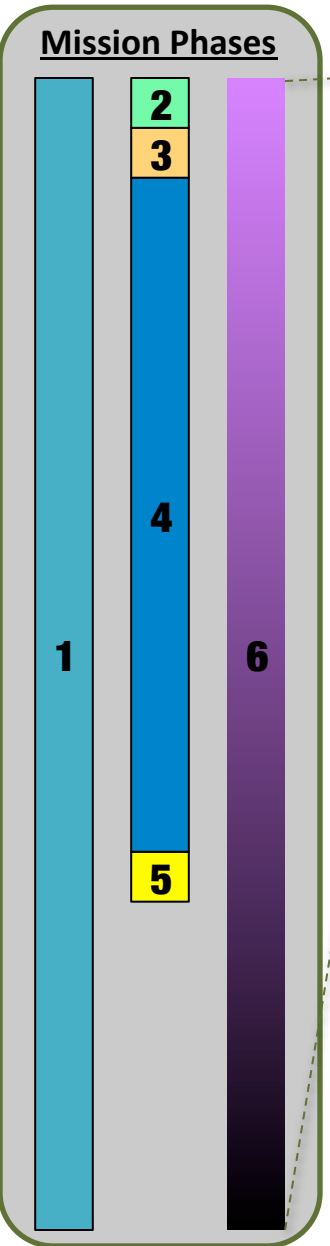
Notional Phase 5 Definition: Preparation for Ascent



Phase 5 Activities (~30 sols)

- Final sample curation (3 crew – 7 sols)
- Prepare MAV for launch (3 crew – 7 sols)
- Transfer all samples to be returned to MAV (2 crew – 1 sol)
- Prepare surface assets for uncrewed operations (2 crew – 3 sols)
- Crew transfer to MAV
- Launch
- Contingency launch window

Notional Phase 6 Definition: Post-Crew Departure



Phase 6 Activities (~TBD sols)

- **Record ascent**
- **Continued exploration with rovers until end of life**
- **Continued operation of deployed instruments and science stations**
- **Potential for sample caching**
- **Potential operation of sample analysis capabilities**
- **Long traverses away from landing site**
  - Relying on PUP power to use visual and spectral imagers, GPR, etc. to extend reach until end of life of rovers
- **Public/educational outreach**

GPR = Ground Penetrating Radar